

AD-A009 077

REASSESSMENT OF THE ALUMINUM BOTTOM CARRIAGE FOR THE
XM198 HOWITZER

Roger W. Powell, et al

Army Armament Command
Rock Island, Illinois

March 1975

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A decision risk analysis was performed to compare the expected cost, schedule, and technical risks of the current development of a steel bottom carriage for the XM198 155mm Howitzer with those of a proposed parallel development of an aluminum version of the bottom carriage. Computerized VERT simulation networks were used to represent the time and technical risk interrelationships among the activities and decision points of the alternative programs. Expected costs were based on an approximation of the planned XM198 buy with the proportion of steel or aluminum carriages determined by alternative production change-over dates.			

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A sensitivity analysis was conducted to determine the effect of a ± 10 percent variation in the risks at the key decision points upon the probabilities of success and the mean-times-to-success for each option.

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CONTENTS

	Page
INTRODUCTION.....	5
DEFINITION OF PROBLEM.....	5
ALTERNATIVE.....	5
ASSUMPTION.....	5
DISCUSSION.....	6
SUMMARY.....	8
CONCLUSIONS.....	9
APPENDIX A.....	11
APPENDIX B.....	21
APPENDIX C.....	41
APPENDIX D.....	47
DISTRIBUTION.....	51

INTRODUCTION

The Project Manager Office, Cannon Artillery Weapons System (AMCPM-CAWS), is considering replacement of the steel-welded bottom carriage for the XM198 155mm howitzer with a monolithic, high-strength aluminum alloy casting as a means of reducing weight and costs. When initial testing revealed design problems that could not withstand certain high stresses, an ad hoc committee was convened August 1974 to review the situation and recommend a course of action to the project manager.

DEFINITION OF PROBLEM

A decision risk analysis was performed (as requested by letter SARRI-L, Appendix A) to determine the following:

- a. The expected cost and risk of continuing the current development of a steel bottom carriage; and
- b. The expected cost and risk of the parallel development of a steel and an aluminum bottom carriage, and the probability of being able to introduce the aluminum version at the scheduled start of the first (July 1978) or the second (July 1979) year of full production of the XM198 howitzer.

ALTERNATIVES

Proceed with the steel bottom carriage which is scheduled to begin development testing/operational testing (DT/OT 2) in January 1975.

Redesign the casting and continue development of the aluminum bottom carriage with the intent of making a production changeover at some later time.

ASSUMPTIONS

The following assumptions were considered while performing this decision risk analysis:

- a. Only two aluminum bottom carriages will be ordered with the second carriage as a backup if the first one fails during the testing.
- b. A January 1975 base point was used to coordinate the resumption of the aluminum bottom carriage development and the start of DT/OT 2 for the XM198 Howitzer.
- c. Because the two development programs would be out of phase, AMCPM-CAWS proposed to evaluate the aluminum bottom carriage with a rigorous durability test (15,000 rounds, effective full charge) in lieu of a complete DT/OT 2.

d. AMCPM-CAWS stipulated that a production changeover to the aluminum bottom carriage later than July 1979, the start of second year of full production, would not be beneficial.

DISCUSSION

Computerized VERT (Venture and Evaluation Review Technique) simulation networks were used to represent the time and risk inter-relationships among the activities and decision points of the alternative programs. Each simulation was subjected to 1000 iterations.

The decision points in these simulations represent scheduled procurement, testing, and review activities in the XM198 program. With each activity there is a time value to accomplish the task and/or risk of successfully achieving the task objective, i.e., complete DT/OT 2. Estimates of these times and/or risks were obtained, as indicated, from the following individuals who are knowledgeable in bottom carriage development programs.

- a. Professor Thomas J. Dolan, consultant, University of Illinois, Urbana, IL.
- b. Mr. H. G. Noble, Jr., - AMCPM-CAWS-TM.
- c. Mr. M. E. Braddock - SARRI-LA.
- d. Mr. Ralph Edelman - Frankford Arsenal, Philadelphia, PA.
- e. Mr. C. R. Shaffer - SARRI-LA.
- f. Mr. R. E. Seamands - SARRI-LR-W.
- g. Mr. J. H. Williams - AMSAR-RDG.
- h. Mr. E. Ryan - AMCPM-CAWS.

Each of these experts was asked to bracket his "most likely" estimate with a "pessimistic" and and "optimistic" one. Risk estimates were obtained from the first six experts. Time estimates came from Mssrs. Braddock, Shaffer, Williams and Ryan.

These estimates were averaged to obtain the following times and risks:

- a. Time required for ordering, delivering, and machining two new aluminum bottom carriage castings was uniformly distributed from 5 to 9 months.
- b. Times required for the following activities were triangularly distributed as indicated:

(1) 4.4, 6.25, and 9.4 months for the durability testing (15,000 rounds, effective full charge) of the aluminum bottom carriage.

(2) 7.25, 9.75, and 12.0 months for the DT/OT 2 of the steel bottom carriage.

(3) 2.1, 3.5, and 5.25 months for ASARC 2.¹

(4) 5.25, 6.5, and 8.25 months for DT/OT 3.

(5) Low rate initial production was 17.8, 20.25, and 24.2 months for the steel bottom carriage and 19.25, 21.25, and 25.0 months for an aluminum bottom carriage.

(6) 1.1, 2.1, and 4.0 months for ASARC 3.

c. A 60 percent probability that an aluminum bottom carriage would successfully complete the 15,000 round, effective full charge durability test.

d. A 80 percent probability that a steel bottom carriage would successfully complete DT/OT 2.

e. A 73 percent probability that an aluminum bottom carriage would successfully complete DT/OT 3.

f. A 92 percent probability that a steel bottom carriage would successfully complete DT/OT 3.

Total and differential costs needed to complete the programs were estimated for the steel carriage and the parallel steel/aluminum carriage development options as shown in Appendix C. All costs have been updated to constant FY 75 dollars. The total costs are based on an approximation of the planned production (actual goal is classified), assuming that all carriages will either be steel or aluminum if a production changeover is made to the aluminum version in July 1978 or 1979. The test costs include the expected number of rounds that AMCPM-CAWS indicated might be expended during DT/OT 2 of the steel carriage (32,300) and the durability testing of the aluminum bottom carriage (15,000).

A sensitivity analysis was conducted to determine the effect of a ± 10 percent variation in the risks at the key decision points upon

¹ Army Systems Acquisition Review Council.

the probabilities of success and the mean times to success for each option. This analysis was performed by systematically increasing or decreasing each risk while holding the other fixed and by changing all of the risks concurrently.

SUMMARY

The results of the analysis are shown in Table 1 and indicate a 73 percent probability of success for the steel-only option with a mean time of 36 months at an estimated total cost of \$27.8M. The parallel development option has an 80 percent probability of success with a mean time of 45 months and an estimated total cost of \$27.7M. With the parallel option, the probability of the aluminum bottom carriage being selected is 67 percent, reflecting the preference given to the aluminum carriage in the analysis. The cost estimated for the parallel effort is a maximum based on the assumption that the production changeover is not made until July 1979. For the parallel development, there is a 20 percent probability that neither a steel nor an aluminum bottom carriage will be developed as opposed to a 27 percent probability of failure for the steel-only option. While its risk is lower than that of the steel-only approach, the parallel option entails a significantly longer mean-development-time. Expected costs were estimated to be about the same for both development programs.

TABLE 1

COMPARISON OF STEEL-ONLY AND PARALLEL PROGRAMS

<u>Development Option</u>	<u>Prob (Option Success)</u>	<u>Prob Steel Being Selected</u>	<u>Prob Aluminum Being Selected</u>	<u>Meantime (mos)</u>	<u>Expected Cost</u>
Steel Only	73%	100%	NA	36	\$27.8M
Parallel Steel/ Aluminum	80%	13%	67%	45	\$27.7M

The criticality of time for both the steel and the aluminum versions of the bottom carriage is illustrated in Table 2 where the probabilities of successful development are related to the scheduled start of the first and second year of production in July of 1978 or 1979, respectively. These probabilities also indicate the risks associated with the prior commitment of funds for the acquisition of the long leadtime items in October of 1976 or 1977.

TABLE 2

AVAILABILITY OF STEEL AND ALUMINUM BOTTOM CARRIAGES

<u>Type of Bottom Carriage</u>	<u>Development Meantime (Months)</u>	<u>Probability of Being Available</u>	
		<u>Jul 78</u>	<u>Jul 79</u>
Steel	36	>99%	>99%
Aluminum	45	57%	92%

The development of the steel bottom carriage has approximately a 100 percent probability of being available by July 1978. With the aluminum version, however, there is only a 57 percent probability of it being available by the same time. The difference reflects the slippage that has occurred in the aluminum effort, and there is even a possibility that this carriage would not be available by July 1979 - the final deadline for a production changeover.

The results of the sensitivity analysis showed that systematically or concurrently varying the risks by ± 10 percent essentially had no effect on the mean time to success for either option. The changes that occurred represent fractional parts of a month with the most variation in the parallel program where the time spread ranged from about 44 1/2 to 45 1/2 months when all risks were changed concurrently. There were changes, however, in the probabilities of success for each option as well as the probability of steel or aluminum being selected in the parallel development. Most of these changes were minor with the biggest difference observed in the steel-only option where the average variance ranged from -8 to +14 percent (see Table D-3, Appendix D).

CONCLUSIONS

There is a high probability that the current steel bottom carriage will be available by July 1978 - the start of the first year of production.

An aluminum version of the bottom carriage would probably not be ready by July 1978, and there is a possibility that it may not be available by July 1979 - the deadline for making a production changeover to the aluminum unit.

A steel/aluminum parallel development program would have a slightly higher probability of success, but this option entails a significantly longer development time.

The expected total costs were estimated to be about the same for the parallel and steel-only development programs.

APPENDIX A

LETTER OF INSTRUCTION



DEPARTMENT OF THE ARMY
ROCK ISLAND ARSENAL
ROCK ISLAND, ILLINOIS 61201

10 September 1974

REPLY TO
ATTENTION OF

SARRI-L

SUBJECT: Ad Hoc Committee for Assessment of XM198 Aluminum
Bottom Carriage Design

SEE DISTRIBUTION

1. Reference:

a. Meeting of subject committee held 27 Aug 74 in the
RIA Commander's Conference Room

b. Letter, 7 Aug 74, Subject: Ad Hoc Committee for
Assessment of Cast Aluminum Bottom Carriage for the XM198
Howitzer.

c. Final Report of Ad Hoc Committee for Assessment of
XM198 155mm Howitzer Aluminum Bottom Carriage Design.

2. Reference 1b. reconvenes this committee, with some changes
in membership, and establishes general guidelines. This LOI
enlarges on those guidelines and establishes more specific
tasks.

3. Reference 1c. recommended a course of action to the
Project Manager, Cannon Artillery Weapons Systems. That
course of action was, in general, accepted and followed until
fundamental errors in the aluminum bottom carriage design
(causing unacceptably high stresses) were discovered. These
made further testing of the existing design a waste of time.
A redesign and new castings are required if work is to proceed.
Additional costs and relatively long time delays inevitably
would be involved. Given these events, the specific assignment
of the committee is to review the situation and again recommend
a course of action to the Project Manager. It is my intent to
follow the same procedures we used in making our first assessment.

4. Per our discussion (ref. 1a.), four courses of action are
to be considered:

a. Continue development of the aluminum bottom carriage
with the intent of substituting it in the XM198 production
runs at some point.

SARRI-L

SUBJECT: Ad Hoc Committee for Assessment of XM198 Aluminum
Bottom Carriage Design

b. Continue development of the aluminum bottom carriage as a PIP for later retrofit.

c. Drop the aluminum bottom carriage work from the XM198 program, but recommend it to be considered as an approach for any future towed artillery system.

d. Drop further consideration of this design approach.

5. Cost and schedule considerations are involved in these alternatives. Production of the XM198 is scheduled to start in October 1975 and continue for three and one-half years. With respect to course of action "a", obviously there is no point in considering introduction of the aluminum bottom carriage to production later than the start of third year production, October 1977. With respect to course of action "b", obviously only an overwhelming technical advantage (e.g., a weight reduction of 500 lbs.) could justify a retrofit program. This possibility was thoroughly discussed and rejected in the initial action of this committee (ref. 1c.). The course of action is included here solely for completeness and needs no further discussion. Courses of action "c" and "d", of course, are largely judgmental at this point since they do not involve a specific design. Any recommendation of either of them, however, must be based on sound technical arguments.

6. As in our first review of this work, what is needed from each committee member is a discussion relative to his area of expertise, of the known facts and, as appropriate, their effect on the courses of action. I will integrate these sub reports into the final report, taking into account the individual recommendations, and circulate it to the committee members for their approval. Discussion of the individual areas of concern follows:

a. Risk Analysis -- (G. Moeller, AMSAR-SAL) This discussion applies only to course of action "a". The cost to be determined is the "most likely" cost (determined as was done with the last review) to (1) continue with the steel bottom carriage, or (2) to introduce the aluminum bottom carriage at the start of second year production (October 1976) or (3) to introduce it at the start of the third year production (October 1977). The probability of successfully completing the production program within cost and schedule for each of these variations is also to be determined. All cost and schedule data should be checked and updated. Data should be obtained from or coordinated with AMCPM-CAWS-PR. Inputs from the other committee members are an essential part of this analysis.

SARRI-L

SUBJECT: Ad Hoc Committee for Assessment of XM198 Aluminum
Bottom Carriage Design

b. Re-evaluation of Aluminum Bottom Carriage Feasibility -- This question (and succeeding ones) are addressed to the remaining members of the committee. In particular, this question was raised by Professor Dolan. Experience with the aluminum bottom carriage since our first evaluation also needs to be taken into consideration. Your answers, of course, bear on all of the alternate courses of action. Producibility, both in the sense of attainable properties and in the probable cost (and practicality) of manufacturing/inspection procedures which will give sound castings, is at issue here. So, too, is the problem of field repair should that be necessary.

c. Development Schedule -- Allowing that a case still can be made that the aluminum bottom carriage is feasible, the most immediate question is whether a realistic development schedule for it can be matched to the XM198 schedule (see para. 6a. above). This is a primary factor in evaluating course of action "a". Given the limitations of theoretical stress analysis of as complex a structure as the aluminum bottom carriage, this question resolves into ones of how many design iterations (with testing) will be required and how long will each take.


d. Advantages to be gained -- As has been noted (ref. 1c.), the expected payoffs from this development are reduced weight and cost. Discussion at our 27 Aug 74 meeting threw both of these into doubt. It appears possible that it will prove necessary to raise the aluminum bottom carriage weight to obtain the required strength and durability. Successive design iterations, with the required testing of each, can quickly eat up expected cost savings. Elaborate inspection procedures which may be required to insure sound castings in production may have a similar effect. Without the advantages of cost and weight savings, there is little reason to go to an aluminum bottom carriage. This question bears on all of the stated courses of action.

7. Attached as inclosures are a nominal time schedule and a short discussion of desired physical properties as requested by Mr. Edelman (SARFA-PDM).

8. Mr. Marvin H. Linn, AMCPM-CAWS-TM (AVN 793-4278/6751) will continue to be the point of contact for all committee business. Requests for additional reference material should be made to him. Arrangements for the planned trip to Yuma Proving Ground to examine the aluminum bottom carriage in service there should be coordinated through him.

FOR THE COMMANDER:

2 Incl
as


HERBERT H. DOBBS
LTC, OrdC
Chairman

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Army Materials & Mechanics Research Center, ATTN: AMXMR-ER,

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Rock Island Arsenal, ATTN: SARRI-L, R. Seamands, Rock Island,
IL 61201

Professor Thomas J. Dolan, University of Illinois, Urbana, IL
61801

CF:

PM-CAWS

NOMINAL TIME SCHEDULE

Ad Hoc Committee For Assessment of
XM198 Aluminum Bottom Carriage Design

(SECOND REVIEW)

Task Assignment	7 Aug 74
Initial Meeting (at RIA)	27 Aug 74
Preparation of Instructions and Data Package	28 Aug - 11 Sep 74
Individual Work by Committee Members	12 Sep - 11 Oct 74
Visit to YPG	to be arranged
Individual Reports to Chairman	14 Oct 74
Preparation of Final Report for Signatures	14-28 Oct 74
Circulation of Final Report for Signatures	28 Oct - 11 Nov 74
Submission of Final Report to PM-CAWS	11 Nov 74

10 September 1974

PHYSICAL PROPERTIES OF MATERIAL
FOR XM198 ALUMINUM BOTTOM CARRIAGE

This subject was discussed with C. Schaffer, SARRI-LA (AVN 793-6232), the project engineer for the XM198 development work at Rodman Laboratory. The required material strength for the XM198 aluminum bottom carriage was determined simply from weight and stiffness considerations; the former dictating maximum stress levels for minimum weight, the latter, for rigidity, setting a limit on these. That limit, with aluminum's modulus of elasticity is 15,000 psi. Allowing a safety factor of 1.2 this gives a desired minimum yield strength of 18,000 psi for a single loading cycle. From this, the minimum tensile limit should be in the neighborhood of 30,000 psi. The elongation originally specified was 3%. Fracture toughness was not specified.

Considering the experimental mechanical properties shown on the attached sheet, the specified stress levels above appear reasonable from the point of view of low cycle fatigue strength.

P.D. 401

CERTIFICATE OF ANALYSIS AND TESTS

CUSTOMER Commanding General DATE 22 May 1972
U.S. Army Weapons Command
Rock Island, Illinois 61201
 Attn: AMSWE-REA-TA YOUR ORDER NO. 72-0-0150
 OUR SALE ORDER NO. 231.131

DESCRIPTION OF MATERIAL

1. 1 pc Bottom Carriage Structure P/N 231-0002 Heat No. A-4 KO-1 Alum
 2.
 3.
 4.
 5.

SPECIFICATIONS

CHEMICAL ANALYSIS

SAMPLE #	C	Mn	P	S	Si	Ni	Cr	Mo	Al	V	Zn	Fe	Mg	Cu	Ti	Sn	Pb	B	W	Sb	Co	Cb
1. A-4		.28			.03				Rem			.04	.23	4.55	.25							
2.																						
3.																						
4.																						
5.																						

MECHANICAL PROPERTIES

Tensile Lbs./Sq. in.	Yield Lbs./Sq. in.	Elong. % in.	Reduction of area %	Hardness	Bend Test
1. 53,600	32,000	14.0%			
2.					
3.					
4.					
5.					

I, a Notary Public do hereby certify
 that this affidavit was subscribed and
 sworn to before me by a duly authorized
 agent of Northern Ordnance Division of
 FMC CORPORATION, on _____
 19____

NORTHERN ORDNANCE DIVISION OF
FMC CORPORATION
 48th & Marshall St. N.E.
 Minneapolis, Minnesota 55421

We hereby certify that the foregoing data
 are the results of tests performed in the
NORTHERN ORDNANCE LABORATORY.
 Northern Ordnance Division of
FMC CORPORATION

560 " 9201

By *C. J. [Signature]*
 Authorized Agent

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NOTE: This letter of instruction states that the critical dates for change-over to the aluminum bottom carriage are either the start of the second year (October 1976) or the third year (October 1977) of production. According to the XM198 milestone schedule, these dates are for the release of long leadtime items for the first and second years of full production which are scheduled to start in July of 1978 and 1979, respectively. Therefore, this analysis determined the cost and risk of meeting the July 1978 and July 1979 production dates.

APPENDIX B
SIMULATION NETWORKS AND
TERMINAL NODE HISTOGRAMS

PART 1 - Steel-Only Development

PART 2 - Parallel Steel/Aluminum Development

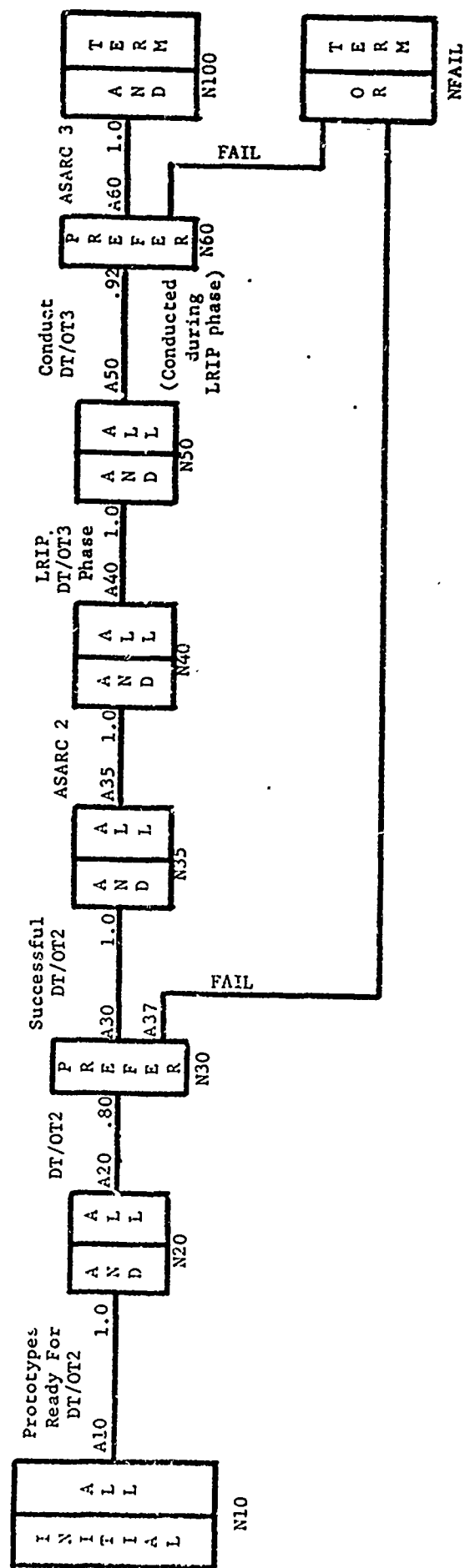


Figure B-1. Flow Diagram Simulating Current Development of the Steel Bottom Carriage for the XM198.

APPENDIX B

PART 1 - STEEL-ONLY DEVELOPMENT

(Arc and Node Descriptions for Figure B-1)

A10	N10	N20	1.0 XM198 PROTOTYPES READY FOR DT/OT 2
A20	N20	N30	0.80 DT/OT 2 WITH STEEL BOTTOM CARRIAGES
A30	SDTIME13.0		7.25 12.0 9.75
A35	N30	N35	1.0 SUCCESSFUL DT/OT 2
A37	N35	N40	1.0 ASARC 2
A40	SDTIME13.0		2.1 5.25 3.5
A50	N30	NFAIL	1.0 UNSUCCESSFUL DT/OT 2
A60	N40	N50	1.0 LOW RATE INITIAL PRODUCTION AND DT/OT 3
A65	SDTIME13.0		17.8 24.2 20.25
ENDARC	N50	N60	0.92 DT/OT 3
N10	N60	N100	1.0 ASARC 3
N20	SDTIME13.0		1.1 4.0 2.1
N30	N60	NFAIL	1.0 UNSUCCESSFUL DT/OT 3
N35			NETWORK INITIATOR
N40			START DT/OT 2 IN JANUARY 1975
N50			BALANCE OF DT/OT 2
N60			ASARC 2 REVIEW AFTER DT/OT 2
ENDNOUE			START LRIP
			START DT/OT 3
			RELIEF NODE FOR DT/OT 3 FAILURE
			NETWORK FAILURE SINK
			SUCCESSFUL DEVELOPMENT OF STEEL BOTTOM CARRIAGE

ANALOR CANNIAGE

7.5232	7.5232	8.7170	9.9108	11.1046	12.2984	13.4922	14.6860	15.8798	17.0736	18.2674	19.4612	20.6550	21.8487	23.0425	24.2363	25.4301	26.6239	27.8177	29.0115	30.2052	31.3990	32.5928	33.7866	34.9804	36.1742	37.3680	38.5620	39.7560
0.0	0.0	0.169	0.307	0.236	0.041	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.004	0.007	0.049	0.041	0.079	0.034	0.019	0.015	0.0	MAX

NO. ORS. = 267 MEAN =

7.5232	7.5232	8.7170	9.9108	11.1046	12.2984	13.4922	14.6860	15.8798	17.0736	18.2674	19.4612	20.6550	21.8487	23.0425	24.2363	25.4301	26.6239	27.8177	29.0115	30.2052	31.3990	32.5928	33.7866	34.9804	36.1742	37.3680	38.5620	39.7560
0.0	0.0	0.169	0.476	0.712	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.757	0.764	0.813	0.854	0.933	0.963	0.985	1.000	0.0

15.6486 STD. DEV. = 10.6694 COEF. OF VARIATION = 0.68

NETWORK TIME FOR MODE M100

ANALYSIS

PDF	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
MIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31.5374	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31.5374	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31.9214	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32.3054	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32.6894	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
33.0734	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
33.4574	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
33.8414	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
34.2254	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
34.6093	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
34.9933	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35.3773	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35.7613	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
36.1453	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
36.5293	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
36.9133	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
37.2973	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
37.6812	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
38.0652	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
38.4492	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
38.8332	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
39.2172	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
39.6012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
39.9852	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40.3692	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40.7531	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
41.1371	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
41.5212	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
41.9052	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

NO. OBS. = 733 MEAN = 36.4108 STD. DEV. = 1.8325 COEF. OF VARIATION = 0.05

26

NETWORK TIME FOR THE COMPOSITE TERMINAL NODE

XMIN CARTRIDGE		CDF										MIN	
POF 0.05 0.10 0.15 0.20 0.25		0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0										0.0	
7.5232	I	7.5232	I	7.5232	I	7.5232	I	7.5232	I	7.5232	I	7.5232	I
7.5232	I	7.5232	I	7.5232	I	7.5232	I	7.5232	I	7.5232	I	7.5232	I
8.8308	I	8.8308	I	8.8308	I	8.8308	I	8.8308	I	8.8308	I	8.8308	I
10.1384	I	10.1384	I	10.1384	I	10.1384	I	10.1384	I	10.1384	I	10.1384	I
11.4460	I	11.4460	I	11.4460	I	11.4460	I	11.4460	I	11.4460	I	11.4460	I
12.7537	I	12.7537	I	12.7537	I	12.7537	I	12.7537	I	12.7537	I	12.7537	I
14.0613	I	14.0613	I	14.0613	I	14.0613	I	14.0613	I	14.0613	I	14.0613	I
15.3689	I	15.3689	I	15.3689	I	15.3689	I	15.3689	I	15.3689	I	15.3689	I
16.6765	I	16.6765	I	16.6765	I	16.6765	I	16.6765	I	16.6765	I	16.6765	I
17.9841	I	17.9841	I	17.9841	I	17.9841	I	17.9841	I	17.9841	I	17.9841	I
19.2917	I	19.2917	I	19.2917	I	19.2917	I	19.2917	I	19.2917	I	19.2917	I
20.5993	I	20.5993	I	20.5993	I	20.5993	I	20.5993	I	20.5993	I	20.5993	I
21.9069	I	21.9069	I	21.9069	I	21.9069	I	21.9069	I	21.9069	I	21.9069	I
23.2145	I	23.2145	I	23.2145	I	23.2145	I	23.2145	I	23.2145	I	23.2145	I
24.5221	I	24.5221	I	24.5221	I	24.5221	I	24.5221	I	24.5221	I	24.5221	I
25.8297	I	25.8297	I	25.8297	I	25.8297	I	25.8297	I	25.8297	I	25.8297	I
27.1373	I	27.1373	I	27.1373	I	27.1373	I	27.1373	I	27.1373	I	27.1373	I
28.4449	I	28.4449	I	28.4449	I	28.4449	I	28.4449	I	28.4449	I	28.4449	I
29.7525	I	29.7525	I	29.7525	I	29.7525	I	29.7525	I	29.7525	I	29.7525	I
31.0601	I	31.0601	I	31.0601	I	31.0601	I	31.0601	I	31.0601	I	31.0601	I
32.3677	I	32.3677	I	32.3677	I	32.3677	I	32.3677	I	32.3677	I	32.3677	I
33.6753	I	33.6753	I	33.6753	I	33.6753	I	33.6753	I	33.6753	I	33.6753	I
34.9829	I	34.9829	I	34.9829	I	34.9829	I	34.9829	I	34.9829	I	34.9829	I
36.2905	I	36.2905	I	36.2905	I	36.2905	I	36.2905	I	36.2905	I	36.2905	I
37.5981	I	37.5981	I	37.5981	I	37.5981	I	37.5981	I	37.5981	I	37.5981	I
38.9057	I	38.9057	I	38.9057	I	38.9057	I	38.9057	I	38.9057	I	38.9057	I
40.2133	I	40.2133	I	40.2133	I	40.2133	I	40.2133	I	40.2133	I	40.2133	I
41.5212	I	41.5212	I	41.5212	I	41.5212	I	41.5212	I	41.5212	I	41.5212	I
41.5212	I	41.5212	I	41.5212	I	41.5212	I	41.5212	I	41.5212	I	41.5212	I

NO. OBS. = 1000 MEAN = 30.8669 STD. DEV. = 10.8267 COEF. OF VARIATION = 0.35

```
OPTIMUM TERMINAL NODE INDEX - NO. ITERATIONS = 1000
I *****-----
INFAIL I *****----- 0.2670
I *****-----
I *****----- 0.7330
I *****-----
I *****-----
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CRITICAL-OPTIMUM PATHS TERMINATING IN THE FOLLOWING NODES HAVE BEEN EXCLUDED FROM THE CRITICAL-OPTIMUM PATH ANALYSIS

NF AIL

ARCS CRITICAL-OPTIMUM PATH INDEX - NO. PAIRS = 733

[illegible]

[illegible]

APPENDIX B (CON'T)
PART 2 - PARALLEL STEEL/ALUMINUM DEVELOPMENT

A10	N10	N20	1.0 ORDER, DELIVER & MACHINE TWO ALUMINUM CARRIAGES
A10	SDTIME12.0	5.0	9.0
A20	N20	N30	1.0 DURABILITY TEST OF 1ST ALUMINUM CARRIAGE
A20	SDTIME13.0	4.4	9.4
A30	N30	N35	1.0 SUCCESSFUL DURABILITY TEST OF 1ST ALUMINUM CARRIAGE
A30	MC	1.60	
A32	N35	N40	1.0 ASARC 2 OF 1ST ALUMINUM CARRIAGE
A32	SDTIME13.0	2.1	5.25
A35	N30	N60	1.0 FAILURE PATH FOR 1ST ALUMINUM CARRIAGE
A35	MC	1.40	
A40	N40	N50	1.0 LRIP AND DT/OT 3 OF 1ST ALUMINUM CARRIAGE
A40	SDTIME13.0	19.25	25.50
A50	N50	N90	1.0 ASARC 3 AFTER SUCCESSFUL DT/OT 3 OF 1ST ALUMINUM
A50	MC	1.73	
A50	SDTIME13.0	1.1	4.0
A51	N50	N60	1.0 UNSUCCESSFUL DT/OT 3 FOR 1ST ALUMINUM CARRIAGE
A51	MC	1.27	
A52	N60	N65	1.0 DURABILITY TEST OF 2ND ALUMINUM CARRIAGE
A52	SDTIME13.0	4.4	9.4
A58	N65	N70	1.0 ASARC 2 OF 2ND ALUMINUM CARRIAGE
A58	MC	1.60	
A58	SDTIME13.0	2.1	5.25
A54	N65	NFAIL	1.0 UNSUCCESSFUL DURABILITY TEST OF 2ND ALUMINUM CARR.
A54	MC	1.40	

A53	N70	NA0	1.0 LRIP AND DT/OT 3 OF 2ND ALUMINUM CARRIAGE
A53	SDTIME13.0		19.25 25.50 21.25
A55	NA0	N90	1.0 ASARC 3 AFTER SUCCESSFUL DT/OT 3 OF 2ND ALUMINUM
A55	MC	1.73	
A55	SDTIME13.0		1.1 4.0 2.1
A56	NA0	NFAIL	1.0 UNSUCCESSFUL DT/OT 3 FOR 2ND ALUMINUM CARRIAGE
A56	MC	1.27	
A60	N90	N100	1.0 SUCCESSFUL DEVELOPMENT OF ALUMINUM BOTTOM CARRIAGE
A70	N100	N200	1.0 TRANSITION TO FULL PRODUCTION OF ALUMINUM CARRIAGE
A100	N10	N15	1.0 DT/OT 2 OF STEEL BOTTOM CARRIAGES
A100	SDTIME13.0		7.25 12.0 9.75
A115	N15	N20	1.0 FAILURE PATH FOR DT/OT 2 OF STEEL CARRIAGE
A115	MC	1.20	
A110	N15	N22	1.0 ASARC 2 FOR STEEL CARRIAGE
A110	MC	1.80	
A110	SDTIME13.0		2.1 5.25 3.5
A116	N22	N25	1.0 LRIP AND DT/OT 3 FOR STEEL CARRIAGE
A116	SDTIME13.0		17.8 24.2 20.25
A117	N25	N40	1.0 FAILURE IN STEEL EMPHASIZES ALUMINUM DEVELOPMENT
A117	MC	1.04	
A118	N25	N60	1.0 FAILURE IN STEEL EMPHASIZES ALUMINUM DEVELOPMENT
A118	MC	1.04	
A120	N25	N100	1.0 ASARC 3 FOR STEEL BOTTOM CARRIAGE
A120	MC	1.92	
A120	SDTIME13.0		1.1 4.0 2.1
A130	N100	N200	1.0 TRANSITION TO FULL PRODUCTION OF STEEL CARRIAGE
FSCAPE	N100	NFAIL	1.0 ESCAPE ARC
ENDARC			
N11	1	2	JANUARY 1975 BASE POINT
N15	2	3	END OF DT/OT 2 FOR STEEL CARRIAGE
N20	4	2	ALUMINUM BOTTOM CARRIAGES READY FOR DURABILITY TEST
N22	2	2	INITIATE LRIP AND DT/OT 3 FOR STEEL
N25	2	3	FINISH LRIP AND DT/OT 3 OF STEEL CARRIAGE
N30	2	3	FINISH DURABILITY TEST OF 1ST ALUMINUM CARRIAGE
N35	2	2	ASARC 2 REVIEW OF SUCCESSFUL ALUMINUM CARRIAGE
N40	4	2	INITIATE LRIP AND DT/OT 3 OF 1ST ALUMINUM CARRIAGE
N50	2	3	ASARC 2 OF SUCCESSFUL ALUMINUM CARRIAGE
N60	4	2	START DURABILITY TEST OF 2ND ALUMINUM CARRIAGE
N65	2	3	INITIATE ASARC 2 REVIEW
N70	2	2	INITIATE LRIP AND DT/OT 3 OF 2ND ALUMINUM CARRIAGE
N80	2	2	ASARC 3 OF SUCCESSFUL ALUMINUM CARRIAGE
N90	4	2	SUCCESSFUL DEVELOPMENT OF ALUMINUM BOTTOM CARRIAGE
N100	6	1	PREFERENCE GIVEN TO ALUMINUM DEVELOPMENT
N110	LINKA60	A70	AL20 A130 ESCAPE
NFAIL	4	1	FAILURE MODE FOR PARALLEL DEVELOPMENT PROGRAM
N200	4	1	SUCCESS MODE FOR EITHER STEEL OR ALUMINUM CARRIAGE
ENDNODE			

NETWORK TIME FOR NODE NFAL

XMI98 CARRIAGE		CDF 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0												
PDF	0.05 0.10 0.15 0.20 0.25	MIN												
15.5106	0.0	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106
15.5106	0.085	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106	15.5106
17.7197	0.229	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197	17.7197
19.9286	0.308	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286	19.9286
22.1376	0.134	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376	22.1376
24.3466	0.005	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466	24.3466
26.5556	0.0	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556	26.5556
28.7646	0.0	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646	28.7646
30.9736	0.0	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736	30.9736
33.1826	0.0	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826	33.1826
35.3916	0.0	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916	35.3916
37.6006	0.015	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006	37.6006
39.8096	0.020	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096	39.8096
42.0186	0.035	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186	42.0186
44.2276	0.090	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276	44.2276
46.4366	0.040	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366	46.4366
48.6456	0.005	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456	48.6456
50.8546	0.0	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546	50.8546
53.0636	0.0	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636	53.0636
55.2726	0.0	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726	55.2726
57.4816	0.0	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816	57.4816
59.6906	0.0	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906	59.6906
61.8996	0.0	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996	61.8996
64.1086	0.0	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086	64.1086
66.3176	0.0	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176	66.3176
68.5266	0.010	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266	68.5266
70.7356	0.025	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356	70.7356
72.9450	0.0	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450
72.9450	MAX	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450	72.9450

NO. OBS. = 201 MEAN = 27.0641 STD. DEV. = 13.0995 COEF. OF VARIATION = 0.48

NETWORK TIME FOR NODE NZ00

XMI98 CARRIAGE		COF													MIN	
POF	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80
32.7403	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
32.7403	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
34.6710	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
36.6017	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
38.5323	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
40.4630	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
42.3937	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
44.3244	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
46.2551	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
48.1858	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
50.1165	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
52.0472	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
53.9779	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
55.9086	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
57.8393	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
59.7700	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
61.7007	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
63.6314	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
65.5621	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
67.4928	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
69.4235	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
71.3542	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
73.2849	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
75.2155	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
77.1462	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
79.0769	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
81.0076	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
82.9384	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0
82.9384	0.021	0.070	0.083	0.165	0.161	0.134	0.073	0.098	0.063	0.038	0.010	0.001	0.0	0.0	0.0	0.0

NO. OBS. = 799 MEAN = 45.0551 STD. DEV. = 9.8831 COEF. OF VARIATION = 0.22

NETWORK TIME FOR THE COMPOSITE TERMINAL NUDE

X4198 CARRIAGE		CDF													MIN	
PDF		0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	1.00
15.5106	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0
15.5106	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.022
18.1040	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.087
20.0974	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.145
23.2907	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.152
25.8841	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.153
28.4775	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.153
31.0708	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.161
33.6642	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.217
36.2576	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.311
38.8510	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.496
41.4443	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.659
44.0377	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.771
46.6311	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.869
49.2244	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.914
51.8178	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.926
54.4112	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.926
57.0045	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.926
59.5979	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.926
62.1913	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.926
64.7846	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.926
67.3780	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.932
69.9714	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.952
72.5647	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.974
75.1581	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.989
77.7515	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.999
80.3448	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.000
82.9384	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.0
82.9384	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	MAX

NO. OBS. = 1000 MEAN = 41.4386 STD. DEV. = 12.8220 COEF. OF VARIATION = 0.31

OPTIMUM TERMINAL NODE INDEX ~ NO. ITERATIONS = 1000

FAIL	I*****	-----	0.2010
200	I*****	-----	0.7990
	I-----	I-----	I-----
	0.1	0.2	0.3
			0.4
			0.5
			0.6
			0.7
			0.8
			0.9
			1.0

ODES CRITICAL-OPTIMUM PATH INDEX - NO. PATHS = 1000

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
10	1.0000									
15	0.1430									
20	0.8630									
22	0.1370									
25	0.1370									
30	0.8630									
35	0.5140									
40	0.5140									
50	0.5140									
50	0.4490									
55	0.4490									
70	0.2700									
30	0.2700									
30	0.680									
100	0.7990									
AIL	0.2010									
200	0.7990									

ARCS CRITICAL-OPTIMUM PATH INDEX - NO. PATHS = 1000

19	0.8570
20	0.8630
30	0.5140
32	0.5140
35	0.3490
40	0.5140
50	0.4200
51	0.0940
52	0.4490
53	0.2700
54	0.1790
55	0.2700
56	0.2480
60	0.0220
70	0.6680
80	0.6680
90	0.1430
100	0.0060
110	0.1370
120	0.1370
130	0.0060
140	0.1310
150	0.1310
160	0.1310
170	0.1310
180	0.1310
190	0.1310
200	0.1310
210	0.1310
220	0.1310
230	0.1310
240	0.1310
250	0.1310
260	0.1310
270	0.1310
280	0.1310
290	0.1310
300	0.1310
310	0.1310
320	0.1310
330	0.1310
340	0.1310
350	0.1310
360	0.1310
370	0.1310
380	0.1310
390	0.1310
400	0.1310
410	0.1310
420	0.1310
430	0.1310
440	0.1310
450	0.1310
460	0.1310
470	0.1310
480	0.1310
490	0.1310
500	0.1310
510	0.1310
520	0.1310
530	0.1310
540	0.1310
550	0.1310
560	0.1310
570	0.1310
580	0.1310
590	0.1310
600	0.1310
610	0.1310
620	0.1310
630	0.1310
640	0.1310
650	0.1310
660	0.1310
670	0.1310
680	0.1310
690	0.1310
700	0.1310
710	0.1310
720	0.1310
730	0.1310
740	0.1310
750	0.1310
760	0.1310
770	0.1310
780	0.1310
790	0.1310
800	0.1310
810	0.1310
820	0.1310
830	0.1310
840	0.1310
850	0.1310
860	0.1310
870	0.1310
880	0.1310
890	0.1310
900	0.1310
910	0.1310
920	0.1310
930	0.1310
940	0.1310
950	0.1310
960	0.1310
970	0.1310
980	0.1310
990	0.1310
1000	0.1310

APPENDIX C

COST ANALYSIS

The expected cost for the steel-only and parallel steel/aluminum development options were estimated as indicated in Figure C-1. These costs are based on an approximation of the planned buy (actual goal is classified) assuming that all bottom carriages will either be steel or a production mix of steel and aluminum carriages. The proportions were determined by assuming that the production changeover to the aluminum version would be made in July of 1978 or 1979. AMCPM-CAWS stipulated that this changeover should not be made later than July 1979, the start of the second year of production.

An inflation factor of 1.16 was used to update the redevelopment (\$4,500,000) and extra test costs (\$1,700,000) from the previous study to constant FY 75 dollars.¹ Test and ammunition costs were then incorporated to represent the 32,300 rounds expected to be fired during the DT/OT 2 of the steel bottom carriage, and the additional 3000 rounds needed for the 15,000-round durability testing of the aluminum version (the extra test costs originally included only 12,000 rounds).

Since the redevelopment cost is an expense occurred only if there is a failure, this cost was adjusted to reflect the probability of failure for each program: 20 percent for the parallel and 27 percent for the steel-only.

The expected cost for the parallel option ranged from \$27.0M to \$27.7M depending on whether the proposed changeover to the less expensive aluminum version was made in 1978 or 1979. Expected cost for the steel-only option was about \$27.8M. The risk for the parallel option is lower but the effort entails a longer mean development time with the result that the production changeover to the aluminum version could not be made by July 1978.

Figure C-2 is a "breakeven" plot of the cost relationship between the parallel steel/aluminum and steel-only development options. It indicates a "breakeven" point between the respective development costs if about 350 aluminum units were produced.

¹ Moeller, Gerald L., Assessment of the XM198 Bottom Carriage. Plans and Analysis Directorate, US Army Weapons Command, March 1973, p. 27.

The equations used to calculate the expected total cost of each development option is as follows:

Steel-only

$$ETC = NS(UCS) + (CPF) (NOR) + (RDT) (1.0 - PPF)$$

Parallel Steel/Aluminum

$$ETC = NS(UCS) + NA(UCA) + (CPF) (NOR) + (RDT) (1.0 - PPF) + TCA$$

Where:

- ETC = Expected total cost of program
- NS = Assumed total buy of steel carriages
- NA = Assumed total buy of aluminum carriages
- UCS = Unit cost of steel bottom carriage
- UCA = Unit cost of aluminum bottom carriage
- CPF = Cost per firing
- NOR = Number of rounds (DT/OT 2 for steel, extra durability rounds for aluminum)
- RDT = Redevelopment and testing cost if current design fails
- TCA = Extra test cost for aluminum carriage development
- PPF = Probability of program failure - (1.0 - .73) for steel-only (1.0 - .80) for parallel steel/aluminum

TABLE C-1
COST ANALYSIS

EXPECTED BUY

<u>Production Dates for Changeover to Aluminum Bottom Carriage</u>	<u>July 78</u>	<u>July 79</u>
Number of aluminum units manufactured =	528	410
Number of steel units manufactured =	442	560
Total number of units	970	970

PROBABILITY OF PROGRAM FAILURE

(1.0 - .80) for parallel development
(1.0 - .73) for steel-only development

COST INPUTS

Cost per Unit

Steel carriage = $1.16 \times \$17,770 = \$20,532$
 Aluminum carriage = $1.16 \times \$12,807 = \$14,856$

Cost per firing (test and ammunition) = \$200
 Expected rounds for DT/OT 2 = 32,300
 Extra rounds for aluminum durability test = 3,000
 Redevelopment and testing cost if current design fails = $1.16 \times \$4,500,000 = \$5,220,000$
 Extra test cost for aluminum carriage development = $1.16 \times \$1,700,000 = \$1,970,000$

COST ANALYSIS

Parallel Steel/Aluminum Development

Total Cost Assuming July 78 Changeover from Steel to Aluminum Bottom Carriage

$528 (\$14,856) + 442 (\$20,532) + \$200 (32,300) + \$5,220,000$
 $(1.0 - .80) + \$1,970,000 = \$26,993,112$

Total Cost Assuming July 79 Changeover from Steel to Aluminum Bottom Carriage

$410 (\$14,856) + 560 (\$20,532) + \$200 (32,300) + \$5,220,000$
 $(1.0 - .80) + \$1,970,000 = \$27,662,880$

TABLE C-1 (Cont'd)

Differential

Jul 79 Changeover Total Cost	=	\$27,662,880
Jul 78 Changeover Total Cost	=	<u>\$26,993,112</u>
Difference	=	\$ 669,768

Steel-Only Development

Number of Units	=	970
Cost per Unit	=	\$20,532
Cost per firing (test and ammunition)	=	\$200
Number of expected rounds for DT/OT 2	=	32,300
Redevelopment and testing cost if current design fails = \$5,220,000		

Total Cost

$$\begin{aligned} \text{Total Cost} &= 970 (\$20,532) + \$200 (32,300) + \$5,220,000 (1.0 - .73) \\ &= \$27,785,440 \end{aligned}$$

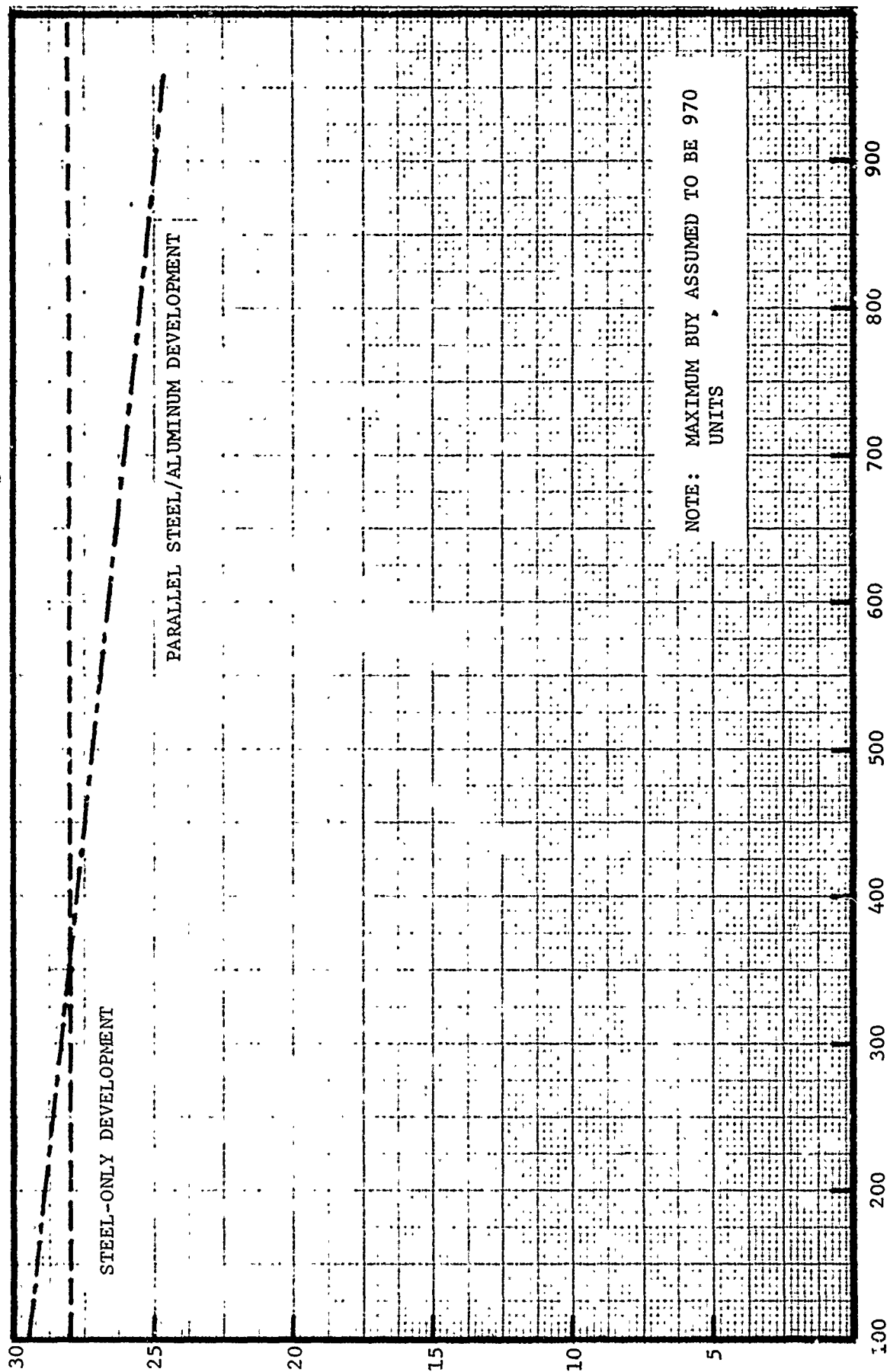


Figure C-2. Cost relationship of steel-only and parallel steel/aluminum development of bottom carriage for XM198.

(Millions of Dollars)

TOTAL COST

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Appendix D

SENSITIVITY ANALYSIS

The mean estimates of risk for the key decision points were subjected to a sensitivity analysis to determine the effect of variations on the probability of success and the mean time to success. This analysis was performed two ways:

- a. Systematically increasing or decreasing each risk by ± 10 percent while holding the other risks fixed.
- b. Concurrently increasing or decreasing all of the risks by ± 10 percent.

The results are summarized in Tables D-1 and D-2.

Decreasing each risk systematically had the overall effect of

- Increasing the probability of success for each development option
- Decreasing the probability of steel being selected in the parallel development option except when the risk represented the DT/OT 2 or DT/OT 3 testing of the steel bottom carriage
- Increasing the probability of aluminum being selected in the parallel development option

Increasing each risk had the opposite effect except again when the operation involved the DT/OT 2 or DT/OT 3 testing of the steel bottom carriage in the parallel development program.

Concurrently decreasing or increasing all risks made the biggest change in the probability of success for each development option and the chance of selecting the aluminum bottom carriage in the parallel effort. The steel-only development program was the most sensitive to changes in the risks.

Changing the risks essentially had no effect on the mean time to success for either option. The changes represent fractional parts of a month with the most variation occurring in the parallel program where the time spread ranged from about 44 1/2 to 45 1/2 months when all risks were changed concurrently.

Table D-3 shows the average change caused by a ± 10 percent variation in the estimated risks for each program.

TABLE D-1

Results of Systematic and Concurrent ± 10 Percent

Variation in Estimated Risks for Parallel

Steel/Aluminum Development Option

Decision Point	Estimated Probability of Success in Base Case (%)	Effect of $\pm 10\%$ Variation in Risks on Indicated Probabilities and Mean Time to Success							
		Prob of Success for Option (%) (79.9)*		Prob of Steel being Selected (%) (13.1)*		Prob of Aluminum being Selected (%) (66.8)*		Mean Time to Success (Months) (45.06)*	
		+10%	-10%	+10%	-10%	+10%	-10%	+10%	-10%
Durability Test 1st Aluminum Carriage 2nd Aluminum Carriage	60	83.9	78.8	12.0	12.5	71.9	66.3	44.93	44.85
		82.1	75.0	12.4	12.8	69.7	62.2	45.32	44.63
DT/OT 2 Steel	80	79.2	78.0	14.1	10.4	65.1	67.6	44.89	45.83
DT/OT 3 1st Aluminum Carriage 2nd Aluminum Carriage	73	80.1	78.6	10.1	13.9	70.0	64.7	44.72	45.64
		80.0	78.7	11.0	15.0	69.0	63.7	45.46	44.23
DT/OT 3 Steel	92	82.4	77.8	13.6	11.6	68.8	66.2	44.91	45.51
All Risks Changed Concurrently		88.6	68.7	10.7	12.6	77.9	56.1	44.52	45.51

* For comparative purposes, figures in parenthesis represent results obtained with the base case analysis.

TABLE D-2

Results of Systematic and Concurrent ± 10 Percent

Variation in Estimated Risks for

Steel-Only Development Option

Decision Point	Estimated Probability of Success in Base Case (%)	Effect of $\pm 10\%$ Variation in Risks on Probability and Mean Time to Success			
		Prob of Success for Option (%)		Mean Time to Success (Months)	
		+ 10%	-10%	+10%	-10%
DT/OT 2	80	81.7	67.6	36.40	36.52
DT/OT 3	92	82.0	67.7	36.45	36.41
All Risks Changed Concurrently		87.4	62.3	36.44	36.46

NOTE: For comparative purposes, results obtained with the base case analysis were a 73.3% probability of success for option with a mean time to success of 36.41 months.

TABLE D-3

Average Change in Probabilities Caused
by $\pm 10\%$ Variation in Risks

Development Option	Average Change in Probability (%)			
	Systematic Change		Concurrent Change	
	Increase	Decrease	Increase	Decrease
PARALLEL PROGRAM				
Probability of Success for Option	1.7	2.6	3.0	4.2
Probability of Steel Being Selected	6.9	3.0	8.5	3.2
Probability of Aluminum being Selected	3.4	2.5	5.3	4.4
STEEL-ONLY PROGRAM				
Probability of Success for Option	11.6	7.7	14.2	10.1